heightened environmental concerns in areas of special scientific interest or environmental conservation. There is a need for greater understanding of how the technique works in order to improve its efficiency. Publicly funded research support in this area would be highly desirable.[19]

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Semiochemicals: Foresight and Hindsight

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Analysis of the potential market share of semiochemicals in integrated crop management is complex and must be seen in the light of other attractive areas of biological and crop science competing for resources. For example, the annual losses and costs of controlling late blight (*Phytophthora infestans* (Mont.) de Bary) of potato alone have been estimated by Centro Internacional de la Papa to be in the order of \$35–50 bn per annum. Around 15% of the world's agrochemicals are applied to cotton crops. Prophylactic nematicide usage across a wide range of fruit and vegetables, from pineapples to parsnips, is becoming a major concern worldwide. The value of UK potato industry for fresh and processed products approaches \$2 bn per annum.

Biological scientists are well aware of the inadequate appreciation by society generally of environmental costs, compounded by the fact that it is difficult to obtain even estimated costs to generate a case for investing in relevant R&D. Environmental accounting is still at a relatively primitive stage. Depressing as it may be, modern-day consumers have little (zero?) tolerance of pests and diseases on commodities; even parasitoids have the capacity to terrify shoppers in supermarkets. Low-cost produce coupled with a

blemish-free and attractive appearance, and year-round supply too, are paramount. It so happens that many agricultural and horticultural practices to achieve these market-driven objectives are simply unsustainable in the medium term. To develop a case for investing in semiochemicals for deployment in integrated crop management schemes, it is essential to carry out rigorous economic and market analyses, identifying the main private and public sector bodies, detailing benefits for specific customers, and forecasting likely technological developments over various timescales. To this must be added socio-economic analyses, potential legislation, consumer trends, scenario-building and networking. In summary, the topic is worthy of its own technology foresight appraisal.

The UK Technology Foresight Programme was first announced in the science White Paper 'Realising our Potential: A Strategy for Science, Engineering and Technology' (Cm 2250), published in May 1993. Its aim was to identify opportunities in markets and technologies which will enhance the nation's prosperity and quality of life.

The Programme commenced in late Spring of 1994 and was spearheaded by a Steering Group and 15 sector panels (Table 1) consisting of representatives from industry, government and academia, set up to explore opportunities in different industrial and service sectors of the economy. Following widespread consultation involving over 10,000 people, the panels published their findings in early 1995. These reports aimed to identify the likely social, economic and market trends in each sector over the next 10–20 years, and the developments in science, engineering, technology and infrastructure required to address future needs.

To date, the main impact of the Foresight Programme has been on the public sector. Government Departments are reflecting the Foresight findings in their development of policy and science, engineering and technology spending decisions. The 1996 Foresight Challenge competition enhanced the interaction between industry and academia. The competition made £92 million available for consortia of business and the science base to undertake projects addressing Foresight priorities. Of this, £62 million was provided by industry. The remaining £30 million was Office of Science and Technology (OST) Challenge funding.

At the end of the analysis phase of the Foresight programme in April 1995, the Agriculture, Natural Resources and Environment (ANRE) panel published its report calling for more investment in priority R&D areas, for ways to be found to overcome barriers to the finance of R&D and for the communication of Foresight priorities to businesses. The recommendations are given below. It also recommended that consideration be given to forming separate panels to cover in more detail the parts of its very broad remit.

Table 1
Technology Foresight Panels, 1994–1995, Phase 1

Agriculture, Natural Resources & Environment
Manufacturing, Production & Business Processes
Defence & Aerospace
Materials
Chemicals
Construction
Financial Services
Food & Drink
Health & Life Sciences
Energy
Transport
Communications
Leisure & Learning
IT & Electronics
Retail & Distribution

Agriculture, natural resources and environment recommendations for investment in R&D

• Animal, microbial and plant biotechnology and cognate sciences underpinning new products and processes in agriculture, horticulture, forestry, aquaculture, pharmaceuticals, land and water remediation, waste management, fossil-fuel processing, and other industries (e.g. molecular basis of plant and animal breeding, pest and disease detection and control, vaccines, metabolic engineering to provide new uses for terrestrial, freshwater and marine crops and animals). This work is crucial for our understanding of how organisms function and develop, is central to integrative bioscience, and exploits the various genome initiatives in plants and animals.

• Robotics; remote sensor and survey systems; predictive modelling in the presence of uncertainty; artificial intelligence and expert systems. These aspects are essential for agriculture, horticulture, exploration and extraction of fossil fuels, mineral and other natural resources, control of pollution and climate change studies.

• Diet and health; more healthy, attractive and better tasting food products from plants and animals, with improved safety and nutritional value, freshness, convenience, appearance and value.

• Improved technology for utilizing forest products, improving wood quality, and finding sustainable substitutes for traditional hardwoods and wood pulps.

• Fin-fish, shell-fish and algae; studies on wild populations and their harvesting, management and utilisation; aquaculture, with particular regard to biotechnology, breeding, diversification, habitats, containment structures, and environment impacts.

• Environmental research programmes encompassing monitoring, surveys, further development of data and information systems, process studies, forecasting, prediction of climatic and geological phenomena, hazard warning and impact evaluation studies.

• Integrated ecosystem management, including maintenance, restoration, and utilisation in the context of terrestrial, aquatic, coastal and oceanic systems. Realisation and understanding of the full value of biodiversity and natural and managed ecosystems including sustainable, terrestrial and aquatic farming systems.

• Technologies for site/soil remediation, landfill management, groundwater cleanup, coastal remediation, reduction, recycling, inactivation, biodegradation, incineration, containment and exploitation of domestic and industrial wastes; measures to prevent, reduce or eliminate exposure to toxic substances and their adverse consequences, techniques to produce, monitor, purify, conserve and distribute potable water, including desalination and other processes.

• Widespread use of life-cycle evaluation and management, and ecodesign principles and practice studies; evaluation of vulnerability of natural resource production and socio-economic systems to climatic, pollution, and land-use changes; clean, cost-effective sustainable technologies; building, urban and transport design to reduce pollution and environmental impacts, and to improve energy use.

• Sustainable resourcing of construction materials and other natural resources (including novel materials, reuse of structures, production and use of biodegradable materials).

• Alternative energy sources, including coal bed methane, shale gas, waves, wind, tides, fuel-producing crops (particularly forest products), geothermal, fuel cells, and in the longer term, gas hydrates.

• Structural changes in agriculture, horticulture and waste management will demand greater vertical and horizontal co-ordination, from fundamental research to the primary producer, processor, retailer and consumer, thereby facilitating the speedy uptake of new ideas and technology (e.g. welfare-friendly systems for livestock; utilisation of animal wastes; fishmeal substitutes; new multi-option, pest- and disease-resistant crops; crops as bioreactors; precision agriculture; greater species and cultivar diversity throughout the year; on-farm added value systems; new bioremediation systems).

• Public and political understanding of science and technology, and of the balance between risk and benefit in applying new technologies, and experts' appreciation of the importance of taking proper account of the public's perspective of their work. There is also a need for legislation, training and advice to be soundly based. These aspects are critical to the biotechology and environmental programmes.

Recognizing the importance of the agri-business sector, in phase 2 of the Programme (late 1995), ANRE was split to form the Agriculture, Horticulture, & Forestry (AHF) panel and two other panels—Natural Resources & Environment and Marine.

The new AHF panel was formed from representatives of levy bodies, trade organisations and companies with major interests in the sector and from the relevant academic communities, together with assessors from public and private sector research sponsors.

The panel's remit for phase 2 was to disseminate the findings of the first phase and to start to promote networking and partnership building between academia and industry. The panel decided that in order to do this, its first task should be to refine the recommendations of ANRE to make them more specific and relevant to the industries it was responsible for. It therefore formed three sub-groups—Plant Systems, Livestock Systems and Forestry & Wood Products—which conducted mini-Foresight analyses of their sub-sectors, based on the work of ANRE. These analyses included assessing the UK's position in world and European markets, its academic and industrial strengths and the priorities for R&D and for infrastructural changes to increase the UK's competitiveness and quality of life. The sub-groups' activities were described in the AHF panel's first report published in November 1996. In 1997, the panel published a discussion document entitled 'A Review of the Rôle of Agriculture, Horticulture and Forestry in the UK Economy' prepared by Professor John Marsh, and the Food Chain Group overarching the work of several other panels was established.

As with other panels, however, these activities have so far largely involved the scientific and technical personnel of companies. The panel intends in phase 3 of the Foresight programme to focus on discussions with non-technical business decision makers. Semiochemicals have not figured to any great extent in the Foresight programme.

My view on semiochemicals in integrated crop management is that the current lines of science are fascinating, of great merit, and worthy of greater recognition.

Integrated pest management schemes are at an early stage even though the concepts have evolved steadily over the past 40 years. IPM systems have been devised for various crops, particularly in the USA, but have yet to take hold in most of Europe. Development of resistance to pesticides, breakdown or absence of host resistance, and the costs and implication of prophylactic agrochemical treatments would indicate a pivotal rôle for IPM in agriculture and horticulture. Nonetheless, certain early failures of IPM to control pests adequately have undermined confidence in this technology.

More effort is required in the monitoring of pests and predators; changes are needed in husbandry practices to foster the overwintering survival of predators, including the provision of ecological refuges and dispersal corridors; treatments that harm predators should be avoided; high-grade predictive modelling and decision-support systems should be generated; economic analyses need to be undertaken to gauge the low tolerance of contamination expressed by the consumer and processor; formulation chemistry of IPM needs to be better developed; a great deal of basic and strategic research needs to be done on semiochemical biosynthesis, receptors, and physiological effects; resistance mechanisms of host plants represent a critical area of investigation, too, exploiting modern genomics.

With hindsight, advances in our understanding and exploitation of semiochemicals have been constrained by low investments in the various areas of relevant science. Agroecology, plant–insect relations, pest/predator monitoring and related modelling systems have not been regarded as high-prority areas, especially as they require funding for periods in excess of two to three seasons. It is still timely to network chemical companies, growers, processors, retailers and economists to develop profitable IPM systems.